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Temperature Effects of an Artificial

HOTSPOT

Embedded in Stored Grain

AMS - 479

U.S. DEPARTMENT OF AGRICULTURE
Agricultural Marketing Service
Transportation and Facilities Research Division

PREFACE

The study on which this report is based is related to other research in progress on grain conditioning and storage, especially to that in which grain temperatures are used as one measure of the results of the studies. The tests described in the report were conducted in grain bins located at the Commodity Credit Corporation Research Bin Site at Watseka, Illinois. The purpose of these tests by research specialists of the Agricultural Marketing Service was to study the effect of localized heating sources in stored grain on the temperature of the surrounding grain.

The work was conducted under the general supervision of Leo E. Holman, supervisory project leader.

Washington, D. C. June 1962

TEMPERATURE EFFECTS OF AN ARTIFICIAL HOTSPOT EMBEDDED IN STORED GRAIN

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SUMMARY

This publication reports observations on the heat-transfer patterns of a heat source buried in shelled corn. Localized heating in stored grain is commonly referred to as a "hotspot" by commercial elevator operators and warehousemen. Since this term has a definite and generally consistent meaning to the grain trade, the heat source used in these tests to simulate heating in stored grain is referred to by the same term.

Local heating in stored grain was simulated by artificial hotspots of two sizes embedded in 3,300-bushel circular steel bins, filled with shelled corn with moisture contents ranging from 12.5 to 13.5 percent. After the shelled corn was cooled by aeration, the electrically heated hotspot was energized and maintained at a surface temperature of about 105° F. The changes in corn temperatures were indicated by thermocouples placed in the grain. Moisture changes in corn above the hotspot were determined periodically by sampling, although this report is concerned primarily with temperature effects.

A 6-inch-diameter hotspot produced temperature increases in corn of 2° F. or more for a distance of about 1½ feet laterally from the hotspot, and 3½ feet above it. Temperature changes of 5° F. or more extended 2½ feet laterally and 4 to 6 feet vertically from a larger 20-gallon oil-filled hotspot. The energy input to the smaller hotspot averaged only 5 watts, while the average input to the larger hotspot varied from 25 to 44 watts in three tests.

The top foot of grain above the larger hotspot increased 3 percent in moisture content during a 165-day test. Lesser increases were measured in shorter tests.

Convection played an important part in the pattern of heat transfer through the grain from the hotspot. The air movement carried heat up from the hotspot and resulted in grain temperature increases extending only half as far laterally from the hotspot as was predicted by calculations based on heat conduction only.

According to these tests, the lateral spacing of thermocouples or other grain temperature measuring systems as now used commercially is generally too wide to detect small hotspots in grain. However, the tendency for hotspots to extend upward toward the surface suggests that the practice of inspecting the grain surface for detection of local heating is effective.

Results of these tests in no way detract from the usefulness of temperature measuring systems for determining average grain temperature, which is important in control of insect and mold growth, or for measuring the variation in grain temperature that leads to moisture changes within the stored grain.

TEMPERATURE AND GRAIN STORAGE

Temperature is second only to moisture content in importance to the successful storage of grain. All stored foods, including grains, keep better at lower storage temperatures. While the effects of temperatures are more critical with perishable "fresh" food, foods such as grain are stored over long periods of time and the cumulative effect of storage temperature on market quality may be great.

Temperature also affects insect activity and mold growth which are the two principal contributors to grain spoilage. Normal winter temperatures in the Corn Belt inhibit mold growth and insect activity, while summer temperatures provide nearly optimum growth conditions. Not only are the propagation and growth of insects and molds dependent upon suitable environmental temperatures, but their activity causes increases in grain temperatures. Temperature changes are often used to detect such storage problems. Insect activity seldom causes grain temperatures to increase above 105-108° F., 1/; mold growth can cause temperatures considerably higher than this. 2/

Uniformity of temperature within the mass of the grain is important in preventing undesirable changes in grain moisture during storage. In the Corn Belt, the difference between normal summer and winter air temperatures may be 50° F. or greater. Where large masses of grain are subject to such seasonal temperature changes, grain in the center of the mass responds to the changes very slowly in comparison to the more exposed grain near the bin walls and top surface. Sufficient temperature differences are established within the grain mass to induce air movement by convection. The air carries moisture from the warmer grain to the cooler grain where it accumulates. This is one of the principal reasons that grain is aerated or turned during long-term storage.

1/ Oxley, T. A. The Scientific Principles of Grain Storage. Liverpool. 1948.

2/ Anderson, J. A. and Alcock, A. W. Storage of Cereal Grains and Their Products. Amer. Assoc. of Cereal Chem. St. Paul, Minn. 1954.

THE PROBLEM AND TEST PROCEDURES

The response of grain to heating from within its bulk, or from its surroundings, is rather complex. Grain has a low thermal conductivity, is granular with air spaces in the mass, and is hygroscopic. Therefore, heat transfer within the stored grain embraces more than one method of heat transmission: (1) Conduction from grain to grain; (2) convection by movement of air through the grain; and (3) transfer of moisture that evaporates from warmer parts of the grain mass and is absorbed or condensed in the cooler parts.

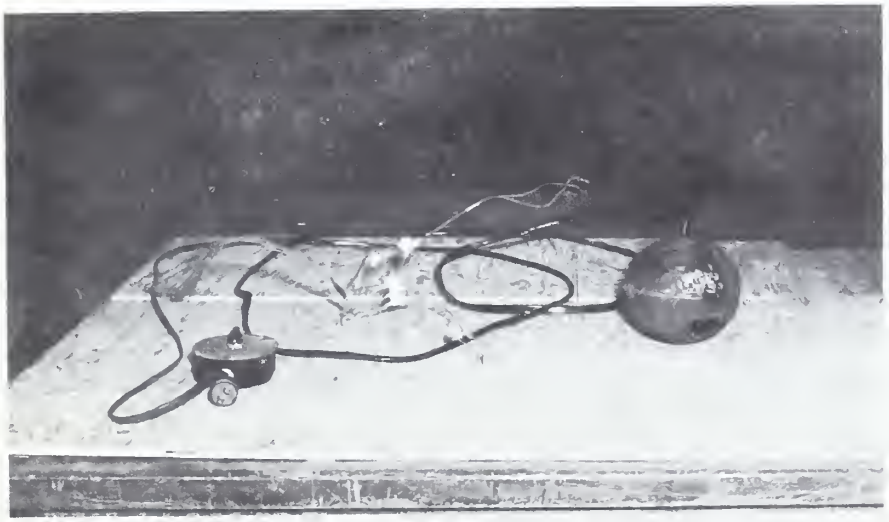
If all heat transfer were by conduction, temperature patterns within the grain mass could be predicted. Oxley 3/, 4/ published values for the conductivity of several grains, and suggested methods of predicting heat losses from stored grain. Oxley also discussed the possible importance of convection and accompanying moisture movement in large masses, but was unable to evaluate these factors in his laboratory tests.

The purpose of this study was to determine experimentally and to present graphically the heat-transfer pattern from a hotspot of fixed size and temperature embedded in a typical bin of shelled corn. There was no attempt at an exhaustive study of the thermophysical properties of the grain bulk; the limited analysis presented serves only to project the observed results to other sizes, types, and conditions of grain storage.

The sizes and temperature of the hotspots were selected to simulate localized heating from insect or mold activity. Four tests were completed with artificial hotspots operated at a temperature of 105° F. The first test used a 6-inch diameter air-filled copper sphere heated with a 25-watt thermostatically-controlled electric heater (fig. 1).

3/ See footnote 1, page 2.

4/ Oxley, T.A. The Properties of Grain in Bulk. III. The Thermal Conductivity of Wheat, Maize, and Oats. Soc. Chem. Indus. Jour. 63: 53-55. London. 1944.



BN 16383

Figure 1.--Six-inch artificial hotspot used in 1957 test.

In succeeding tests, the hotspot was a 20-gallon galvanized tank filled with SAE 20 motor oil (fig. 2). The oil was heated with a 130-watt immersion-type electric heater controlled with a thermostat.

Each of the hotspots was installed close to the center of a circular steel grain bin, 18 feet in diameter, with walls 16 feet high (fig. 3). The bins were filled to a depth of about 15 feet with shelled corn having a moisture content ranging between 12.5 and 13.5 percent. Aeration was used to establish a uniform grain temperature at the start of the text. The bins were located at the Commodity Credit Corporation Research Bin Site at Watseka, Illinois.

The temperature of the hotspot and of the surrounding grain was sensed by thermocouples and measured with a portable potentiometer. Seventeen thermocouple cables were spaced equally in a vertical plane starting at the hotspot and extending to the bin wall (fig. 2). Each cable was made up of thermocouples 6 inches apart. This combination produced a 6-x 6-inch grid along the bin radius. Thermocouples also were attached to the outside of the hotspot at the top, bottom, and midway on the side. For the 1958 test an additional cable with thermocouples spaced 6 inches apart was installed from the top center of the hotspot vertically to the surface of the grain.

The 6-inch hotspot was installed after the bin was filled by sinking an 8-inch-diameter pipe in the center of the bins, removing corn from the pipe by suction, and then installing the hotspot through the pipe. The hotspot was positioned about 8 feet below the surface of the grain, and then the pipe was withdrawn. With this method of installation, the positioning of the hotspot, with respect to adjacent thermocouples, was not exact.

The larger hotspot was installed after the bin was approximately half-full. The hotspot was positioned adjacent to the grid of thermocouples (fig. 2), and the bin was then filled to the level of the top thermocouples. After two tests, the hotspot was moved to a similar bin equipped with a larger aeration fan, where it was installed in the same way.

In all installations, the energy was supplied to the hotspot through a flexible electric cable extending from the top of the grain. A watt-hour meter was used to record the energy input. The thermostat was preset to maintain the surface of the hotspot at 105° F.

Before the tests were started, the corn was cooled by aeration to a temperature as uniform as weather conditions permitted. In the third test corn was cooled to about 15° F., while in all other tests the corn temperature after cooling ranged from 32° F. to 44° F. After an initial set of grain temperatures was taken, operation of the hotspot was started. Temperatures of the hotspot and of the grain were taken daily at the start of the tests and less frequently as the tests progressed. Energy consumption was recorded each time the temperatures were read.

Grain moisture determinations were made at the start of the tests and at approximately monthly intervals. Moisture contents were determined from samples taken from each foot to a depth of 5 feet below the surface at the center of the bin, at the outer wall, and halfway between.

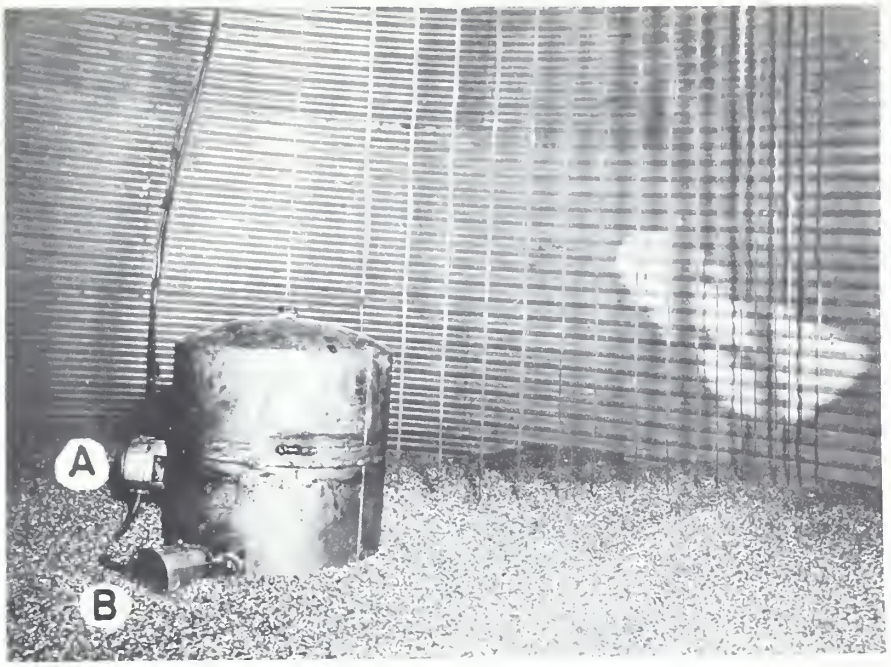


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Figure 2.--The hotspot positioned adjacent to the thermocouple cables in the half-filled bin; A - thermostat, B - heater.

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Figure 3.--The hotspot tests were conducted in these 3,300-bushel grain bins.

HOTSPOT OPERATION AND TEST RESULTS

The hotspot was operated for periods of 30 days or more without interruption during each of the four tests. Length of the tests and operating conditions are listed in table 1.

Table 1.--Hotspot test periods and operating conditions

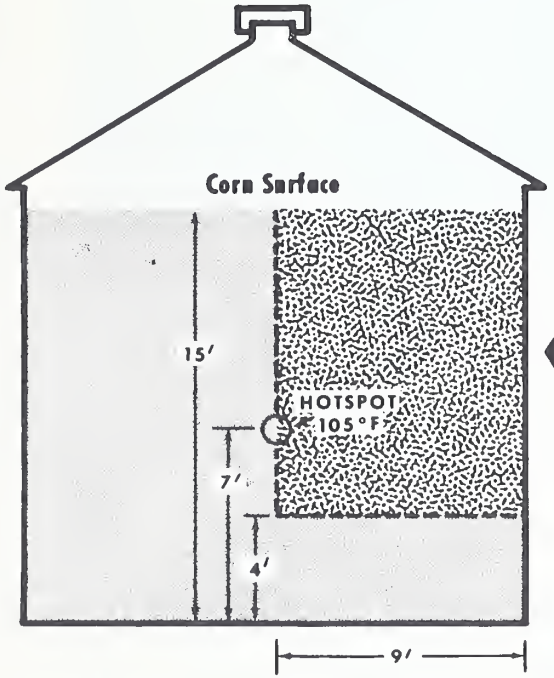
Year	Test started	Test period	Initial grain temperature	Average for test period: Outdoor temperature	Average for test period: Energy input
	Date	Days	° F.	° F.	Watts
1957.....	Feb. 13	72 1/	38	37	5
1958.....	Jan. 14	49 2/	32	26	35
1960.....	Jan. 25	32	15	26	44
1960-61.....	Nov. 18	165	44	35	25

1/ Hotspot (6-inch) operation was interrupted March 16 to 19.
2/ Hotspot (20-gallon) operation was interrupted March 3 to 10.

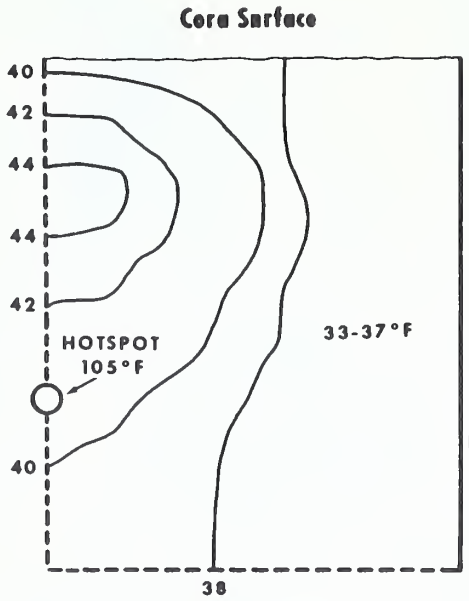
The 6-inch hotspot operated from February 13 to March 16, 1957. Grain temperature patterns are shown in figure 4. After 21 days of operation the 42° F. isotherm (equal temperature line) was located 1½ feet below and to the sides of the hotspot and 3½ feet above. The operation of the hotspot was interrupted by a power failure for 3 days before the next temperature readings were taken. The increased temperatures surrounding the hotspot were almost completely dissipated during the 3-day interruption. Subsequent operation for 51 days did not provide any greater temperature increase in the grain than that shown after 21 days of operation. The energy input to the hotspot averaged 7.8 watts for the first 5 days and 4.5 watts for the remainder of the test.

The larger hotspot, equal to about 2 bushels in volume, was put into operation on January 14, 1958, after the corn had been cooled to an average temperature of 32° F. The corn adjacent to the hotspot was initially somewhat warmer than the average and ranged from 35° to 40° F. (fig. 5). After 8 days of operation, grain temperatures had increased 5° F., or more, 1 to 1½ feet laterally from the hotspot, and 2½ to 3 feet above it. After 17 days of operation, the same temperature increase extended 2 feet laterally and about 4 feet above. The temperature effect of the hotspot extended downward about half as far as it extended laterally. Temperature patterns in the grain at selected times during the test are shown in figure 5.

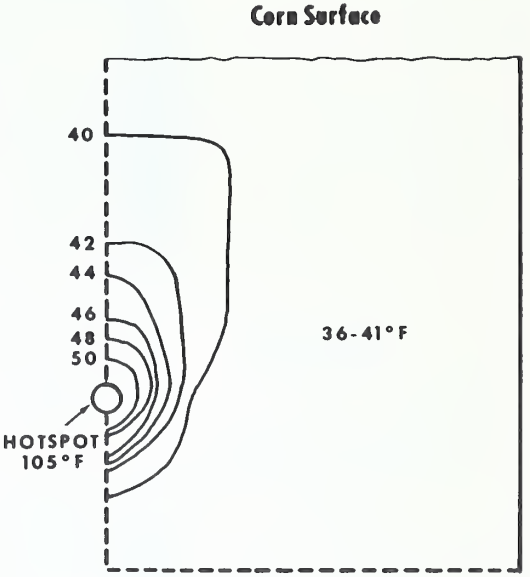
CORN TEMPERATURE PATTERNS DURING 1957 HOTSPOT TEST



The dark area in the filled bin indicates the location where the corn temperatures were taken.



Initial grain temperatures



After 21 days of operation

Figure 4

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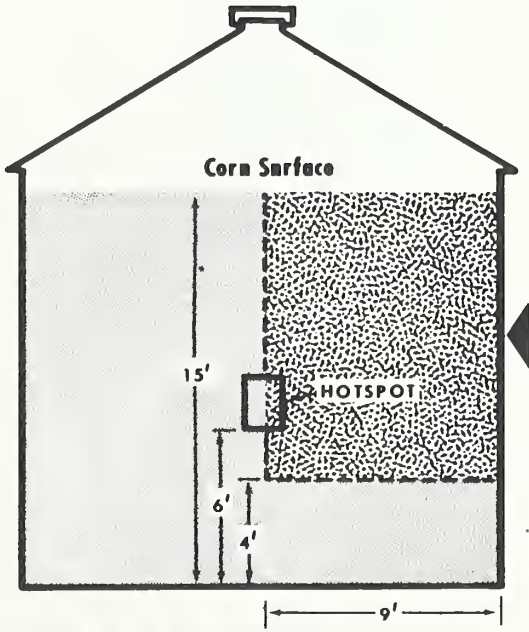
CORN TEMPERATURE PATTERNS DURING 1958 HOTSPOT TEST



The dark area in the filled bin indicates the locations where the corn temperatures were taken

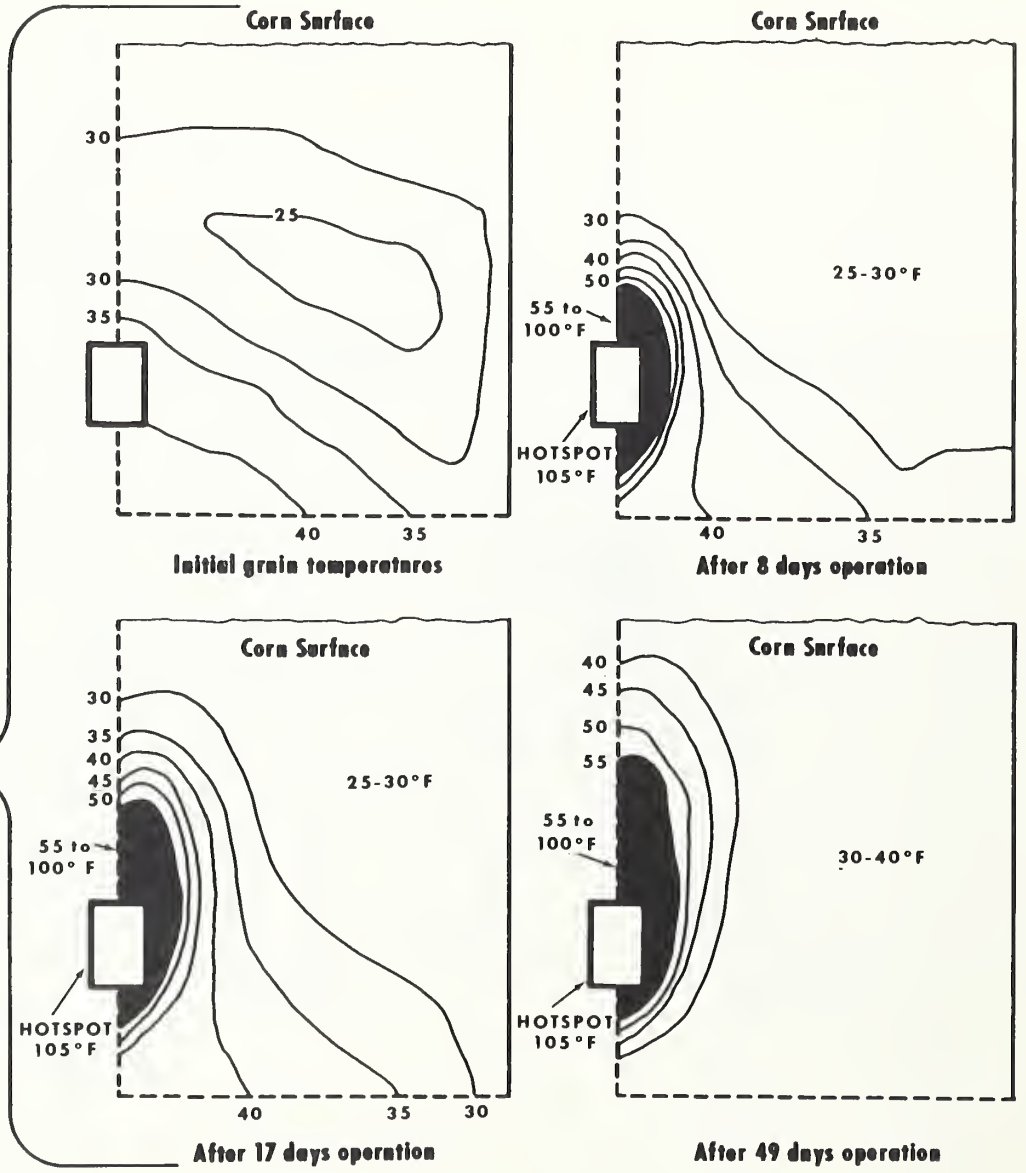


Figure 5

BN 16390

Twenty-one days after this test was started, operation was interrupted by a faulty electrical connection for a period of about 1 week. The repairs were made on the afternoon of February 10, and the test was resumed. About 3 days of hotspot operation were required to regain the temperature pattern recorded 4 days before the interruption. The test was stopped on March 11, after 26 days more. At that time, the 40° F. corn temperature line was positioned about 2½ feet laterally from the side of the hotspot and 7 feet above it--almost to the corn surface. The energy input to the hotspot averaged 35 watts. The energy consumption in kilowatt-hours during the test period is shown in figure 6.

The moisture content of the corn was measured at monthly intervals in the 1958 test. Samples were taken from each of the top 4 feet of corn at the bin center and halfway between the center and the wall. The moisture in the top foot of grain at the center and above the hotspot increased from 14.1 percent to 15.1 percent during the test. This compares with 0.2 percent increase in the top foot at the other sampling location. No measurable moisture changes occurred below the top foot.

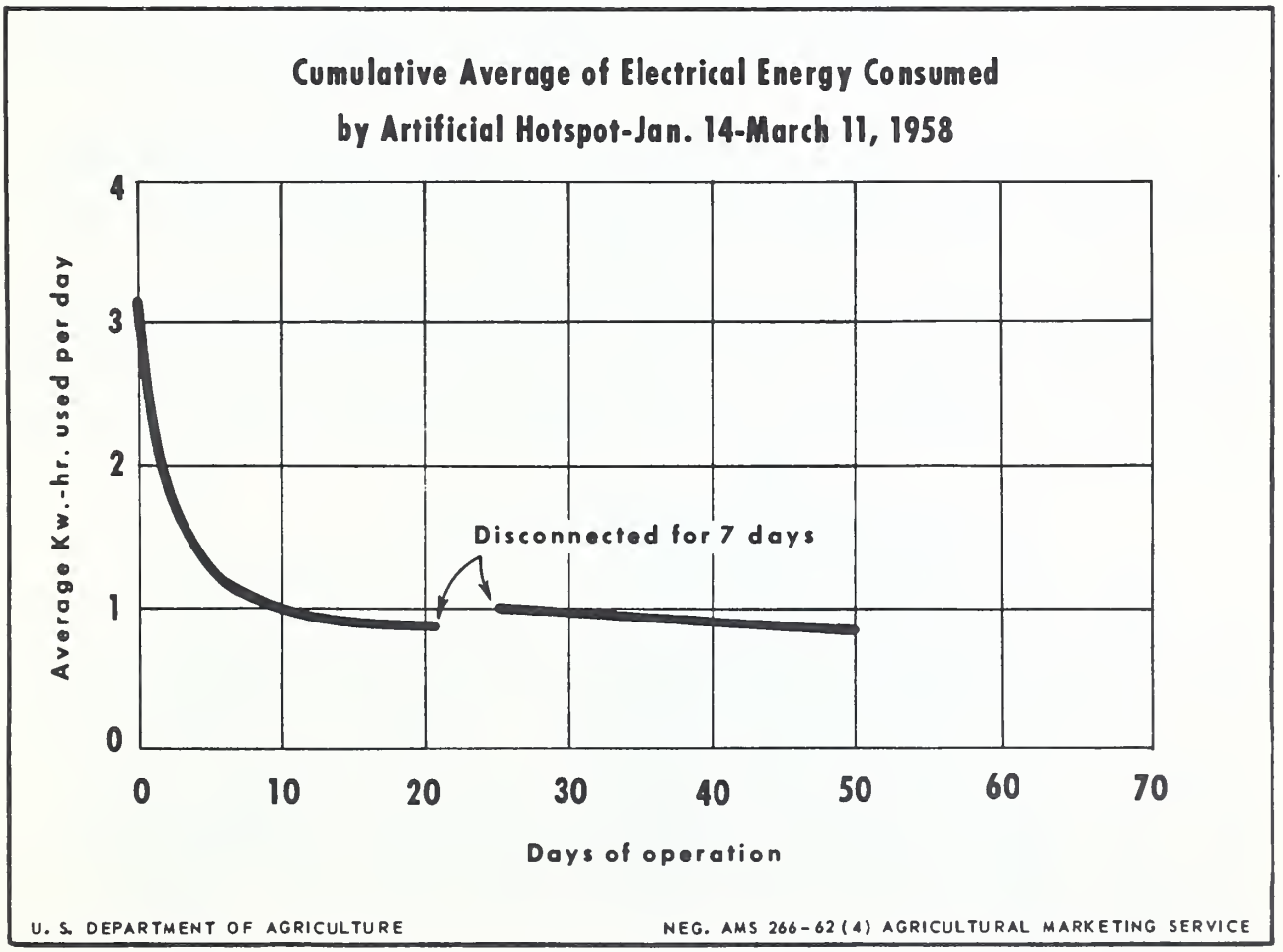


Figure 6

The third test was started January 25, 1960, with the corn cooled to an average temperature of 15° F. The corn temperature adjacent to the hotspot was below 10° F. After 2 weeks, the corn above the hotspot had warmed to 25° F., or more. By the end of the test period, February 26, the 25° F. isotherm extended about 7 feet above the hotspot--almost to the grain surface, and 2 to 2½ feet to the side of the hotspot (fig. 7). The energy input to the hotspot averaged 44 watts for the test period. With initial corn temperatures below 10° F., the full 130-watt capacity of the heater in the hotspot was used during the first 24 hours.

The fourth test began in the fall of 1960. The hotspot was started on November 18, and operated without interruption until May 2, 1961--a test period of 165 days. The initial corn temperature averaged 44° F. with the corn in the lower part of the bin adjacent to the hotspot about 5° F. warmer than the average (fig. 8). After 10 days, corn temperatures had increased to 55° F. at a distance of 1 to 1½ feet laterally from the side of the hotspot and from 1½ to 2 feet above it. With lower outdoor temperatures in the winter, much of the grain in the bin, except that in the center near the hotspot, cooled to 35° F. or below (fig. 8). All grain above the hotspot was 50° F. or warmer by the end of the test on May 2. However, the amount of corn with a temperature of 55° F. or higher was not much greater than it was 10 days after the hotspot was started. The changes in grain temperature during the test are illustrated in figure 8.

The energy input to the hotspot averaged 25 watts for the 165 days of this test (table 1). The energy input for the first 3 days was about double the average. Energy consumption was less than in the 1958 test, and reflects in part higher average outdoor temperatures during the test period.

Moisture changes in corn above the hotspot indicate considerable moisture movement associated with the temperature variation that was established and maintained by the hotspot. In the center of the bin, the moisture content of the top 1 foot of grain increased from 16 percent when the hotspot was started to 19 percent 3 months later. Moisture changes in the top 4 feet of corn are shown graphically in figure 9.

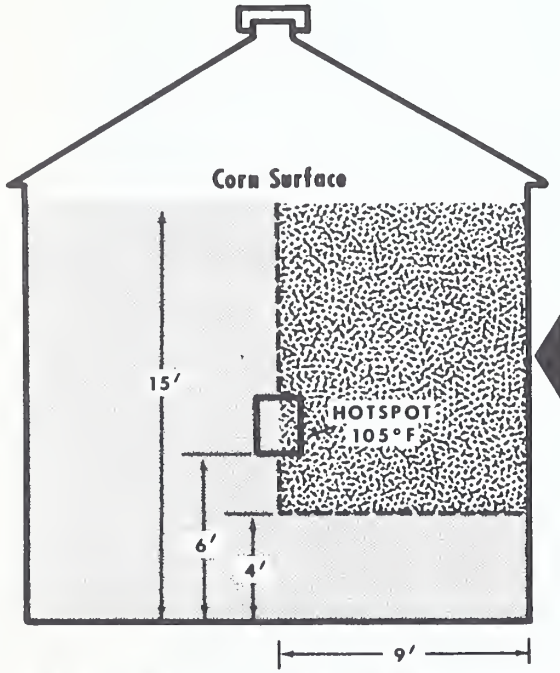
SOME ANALYSES AND PROJECTIONS

The experimental data presented are limited in application by test conditions. To generalize from these test results, the effect of both hotspot size and bin size on grain temperature changes must be known or estimated. Oxley 5/, in his discussion of spontaneous heating of stored grain, used a spherical grain bulk for heat transfer calculations. He suggested that a sphere is the approximate thermal equivalent of a cube of grain where the diameter of the sphere and side dimensions of the cube are equal. Oxley 6/, used the scheme of a small heated sphere in the center of a larger sphere filled with grain to determine experimentally the values for thermal conductivity of grain. However, Oxley's calculations considered heat transfer by conduction only.

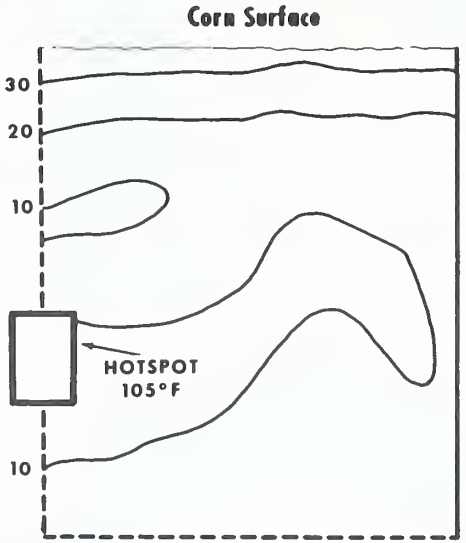
5/ See footnote 1, page 2.

6/ See footnote 4, page 3.

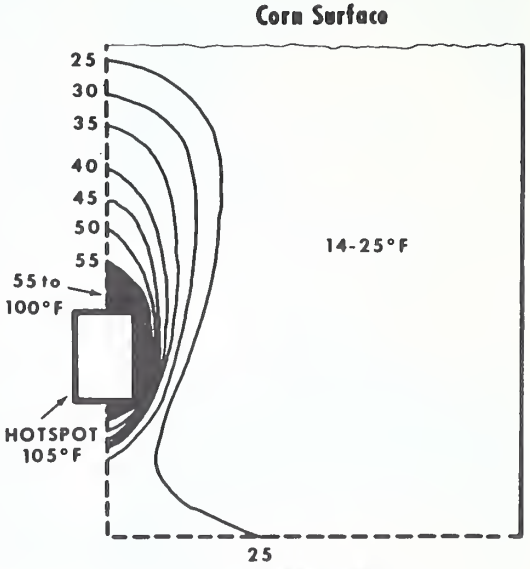
CORN TEMPERATURE PATTERNS DURING 1960 HOTSPOT TEST



The dark area in the filled bin indicates the locations where the corn temperatures were taken



Initial grain temperature



After 32 days operation

Figure 7

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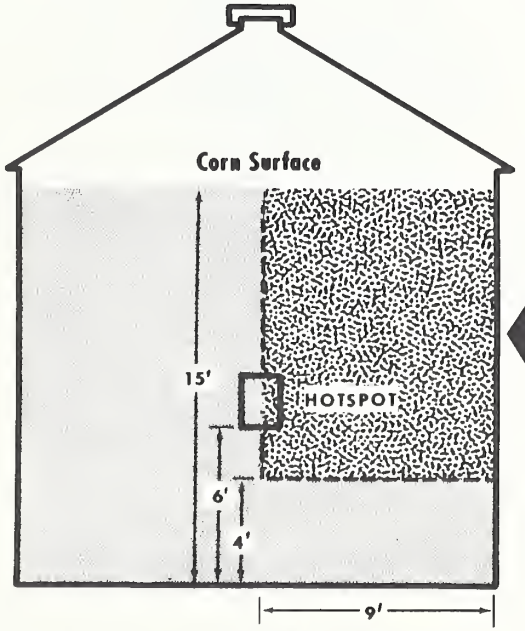
CORN TEMPERATURE PATTERNS DURING 1960-61 HOTSPOT TEST



The dark area in the filled bin indicates the location where the corn temperatures were taken

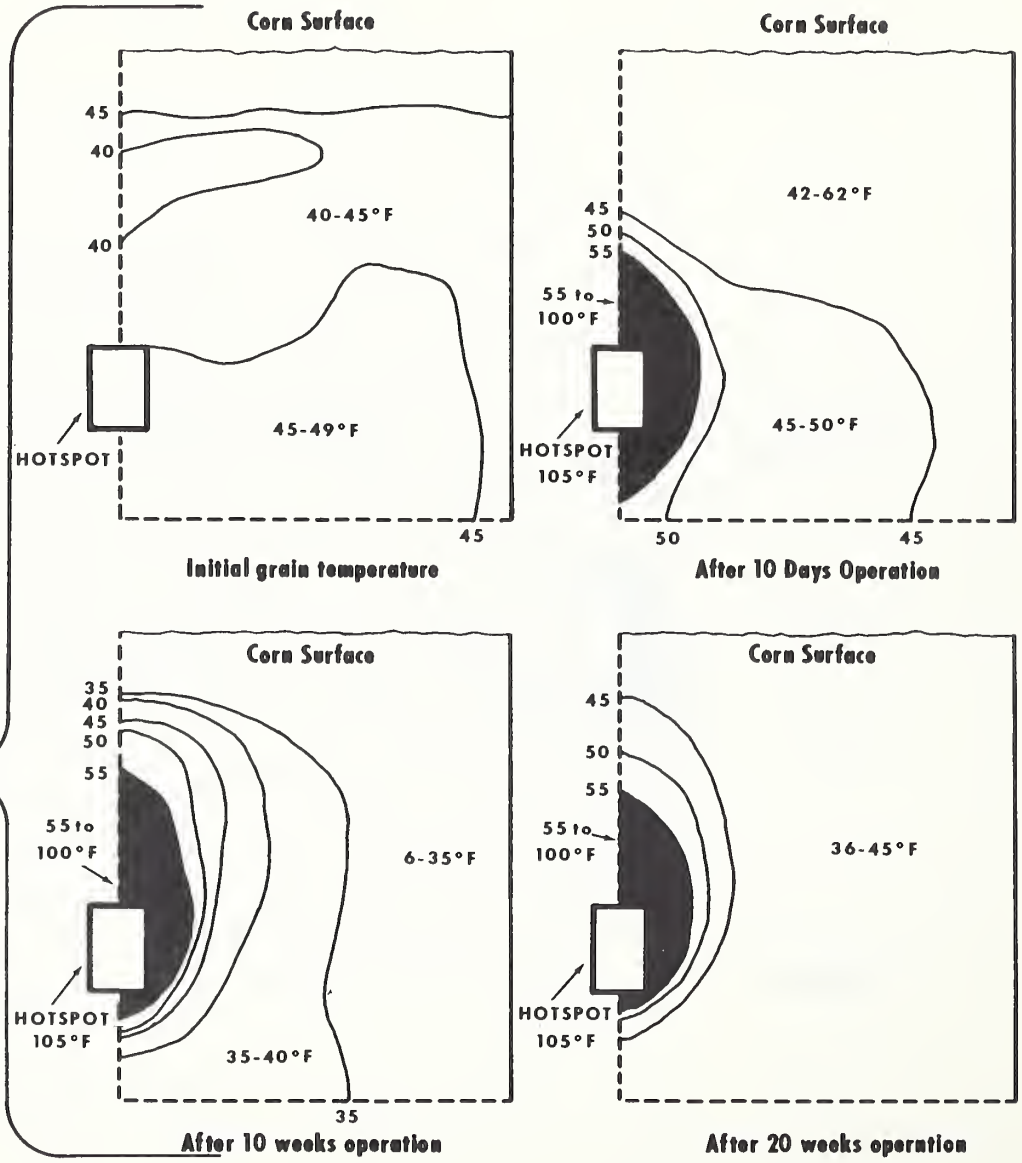


Figure 8

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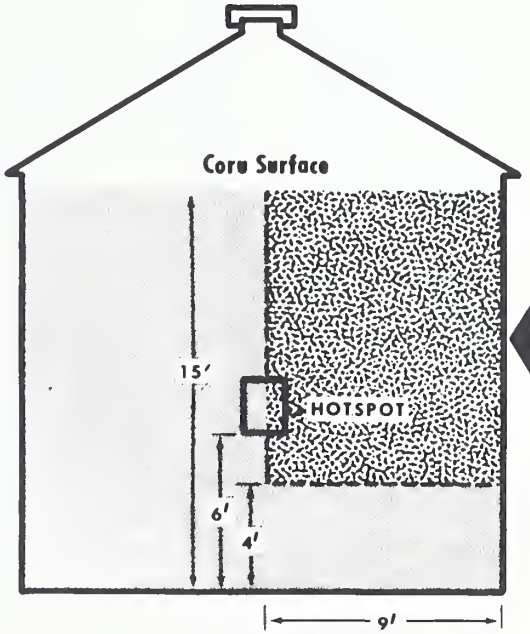
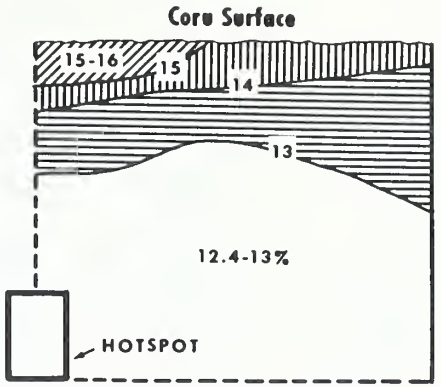
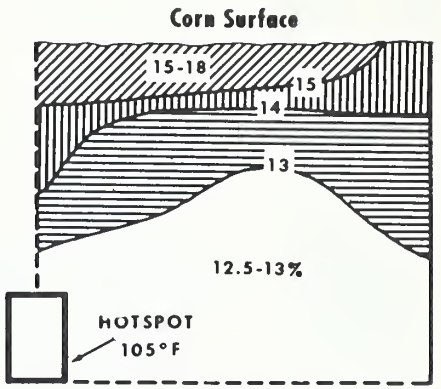
MOISTURE CHANGES IN THE CORN ABOVE THE HOTSPOT DURING THE 1960-61 TEST



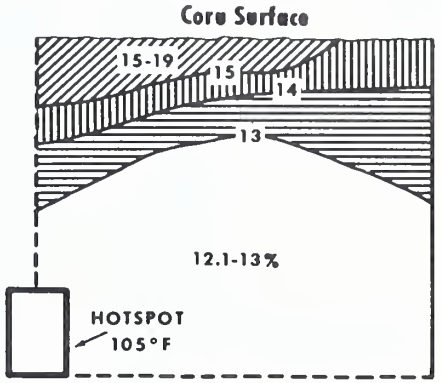
The dark area in the filled bin indicates the location where moisture samples were taken



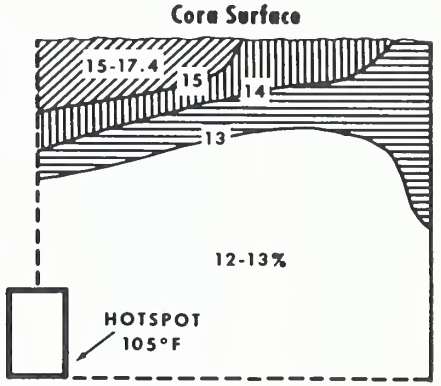
Initial grain moisture percent



After 14 days operation



After 47 days of operation



After 165 days of operation

Figure 9

BN 16386

Heat transfer by convection obviously was important in the establishment of temperature patterns observed in tests with the artificial hotspot. However, calculations based on heat conduction in a spherical bulk are useful in indicating the direction, if not the magnitude, of changes that could be expected under different conditions of hotspot size, bin size, and ambient temperature.

The amount of energy input to the hotspot was shown in table 1. Assuming a spherical hotspot with a radius of 0.86 feet (similar to the large hotspot used in the tests), centrally located in a spherical grain mass that is 9 feet in radius, the energy input at steady-state conditions was calculated 7/. The value for thermal conductivity of corn used was 0.1 B.t.u. per hour per foot per degree Fahrenheit. The comparison between actual energy input in watts observed in the study and that calculated is as follows:

Year	Observed watts	Calculated watts
1957	5	6
1958	35	26
1960	44	28
1960-61	25	21

Except for the 1957 test with the 6-inch hotspot, observed energy input was greater than that calculated. Included in the observed values was the energy required for the initial warming of the grain.

The temperature gradient through the grain was also calculated for the simulated conditions described above (fig. 10). Under the assumed conditions, a minimum temperature change of 10° F. should extend 3.75 feet from the center of the hotspot and a 5° F. change should extend 5.25 feet after the grain had warmed to steady-state conditions.

Figure 11 shows the calculated effect of the size of hotspot, at a specified temperature, on the distance from the hotspot center where a 10° F. increase in temperature of the corn occurs. This is shown for an 18-foot diameter and for a 100-foot diameter spherical grain bulk. As the hotspot is increased in size, the temperature influence extends farther into surrounding grain. For example, with a hotspot 4 feet in diameter, a 10° F. or greater corn temperature change is calculated to extend 6 feet from the hotspot center in an 18-foot diameter sphere and 10.5 feet in a 100-foot diameter sphere.

In the tests reported, a 10° F. or greater temperature change extended only about 2 feet, or about half as far laterally as predicted by the calculations. The temperature effect downward was less. Only above the hotspot did the temperature pattern extend as far from the hotspot as had been calculated. This shows that convection played an important part in the pattern of temperatures around the hotspot. The convection of heat upward toward the grain surface increased the heat loss to the outside. This probably accounts for the observed energy input to the hotspot approximating the calculated amount, while the temperature change in the grain was substantially less than calculated. No attempt was made to evaluate the resistance to heat transfer between the metal hotspot and the grain.

7/ Jacob, Max. Heat Transfer, Vol. I. New York. 1949.

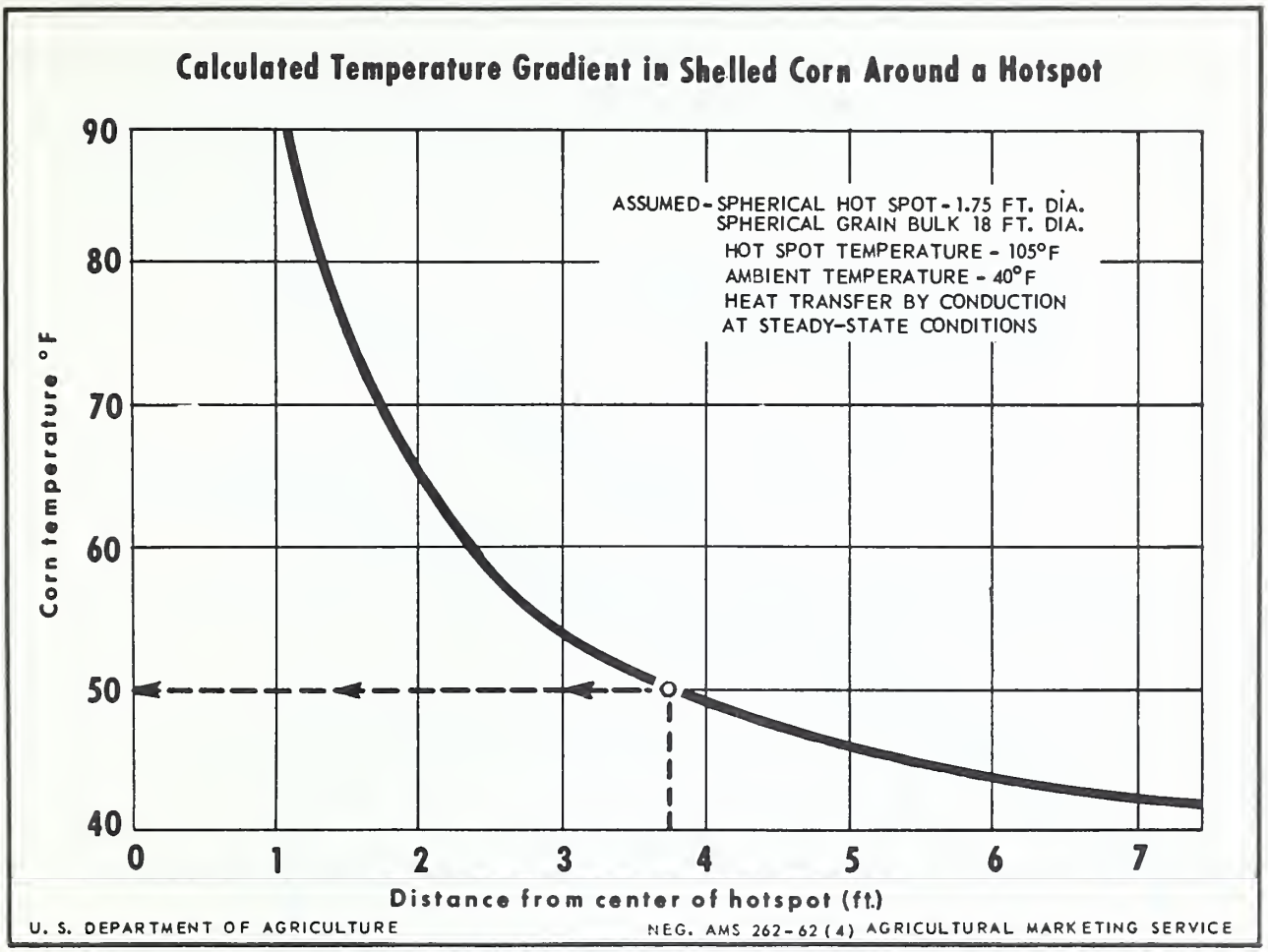


Figure 10

APPLICATION OF RESULTS

The temperature patterns observed in grain around a hotspot of fixed size, show that the lateral movement of heat from the hotspot is limited, and is less than half that predicted by heat-conduction equations. The upward movement of heat from the hotspot is aided by air movement within the grain mass, and tends to extend the heating area to the surface. The results of these tests confirm the usefulness of the practice of inspecting the grain surface for indications of heating.

The location of the hotspot within the grain bulk affects the temperature changes in the surrounding grain. Obviously, the heat from a hotspot near the grain surface will be more rapidly dissipated to the outside. On the other hand, if heating grain is buried deep within a large grain mass, most of the heat produced will be reflected in temperature changes in the surrounding grain.

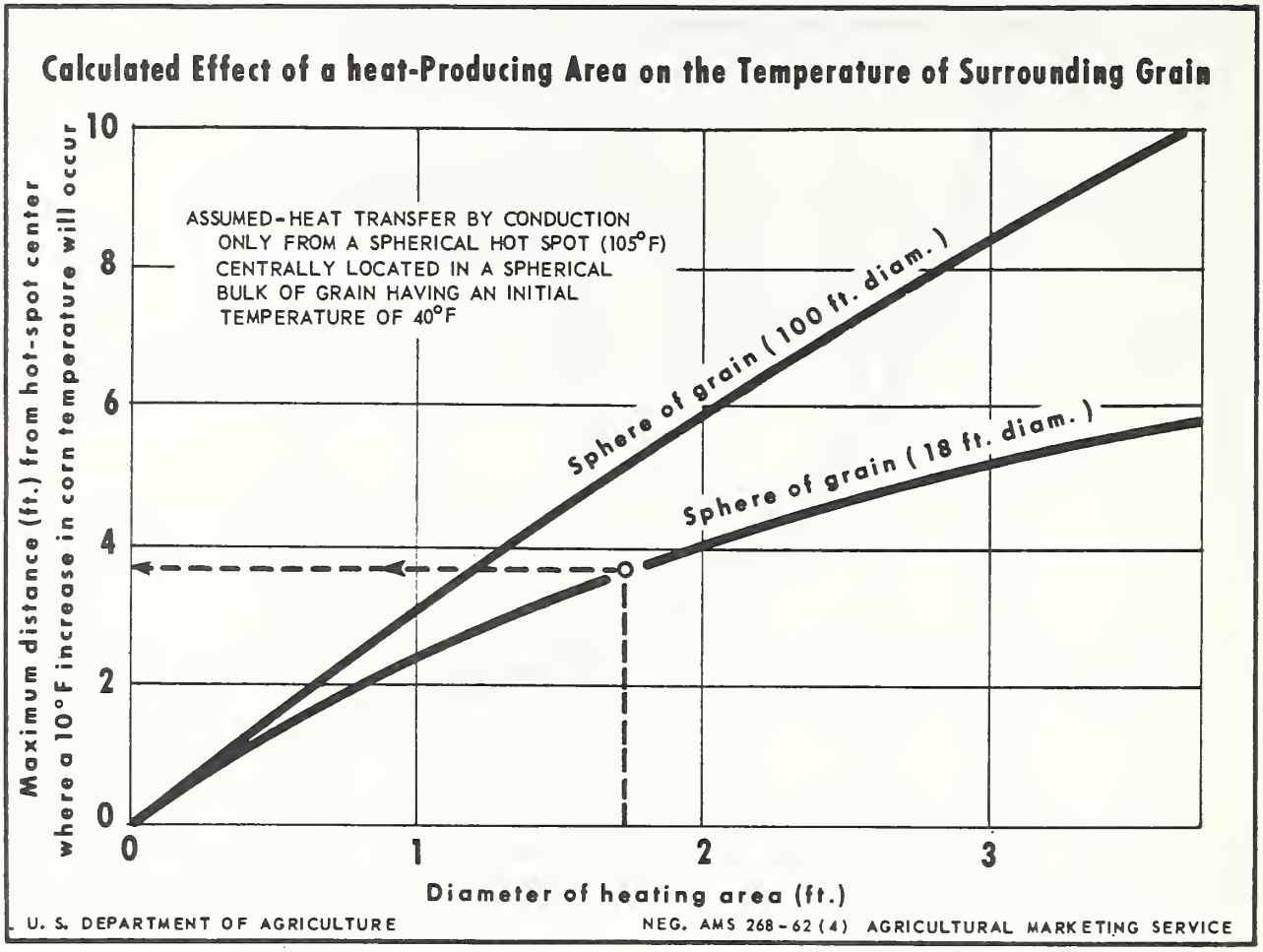

Calculated Effect of a heat-Producing Area on the Temperature of Surrounding Grain
Maximum distance (ft.) from hot-spot center where a 10°F increase in corn temperature will occur
ASSUMED-HEAT TRANSFER BY CONDUCTION ONLY FROM A SPHERICAL HOT SPOT (105°F) CENTRALLY LOCATED IN A SPHERICAL BULK OF GRAIN HAVING AN INITIAL TEMPERATURE OF 40°F
Sphere of grain (100 ft. diam.)
Sphere of grain (18 ft. diam.)
0
2
4
6
8
10
0
1
2
3
Diameter of heating area (ft.)
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Figure 11

Permanent grain temperature sensing systems are used in most storages where grain is held for more than a few weeks. Generally these are installed by suspending a cable containing temperature measuring points (usually thermocouples) from the roof of the storage. The thermocouples are usually spaced 3 to 8 feet apart on the cable. Single cables are used in the center of the circular bins or tanks up to about 25 feet in diameter. In large-diameter tanks and flat-storage buildings, the cables are spaced about 20 feet apart. The number of thermocouples per cable can be increased at a cost considerably less than that of increasing the number of cables. The lateral distance between thermocouples is generally too great to sense the type of grain temperature changes observed in these tests. If small heating areas, such as those resulting from roof leaks, are to be detected, the lateral spacing needs to be reduced by about one-half. The cost of providing the additional cables is probably prohibitive with the types of grain temperature measuring systems now in use.

It should be emphasized that grain temperature measurement systems are valuable in other ways than detecting small heating areas. They are used to determine the average grain temperature, which is important in the control of mold and insect growth; to determine variation in grain temperatures that leads to moisture migration and accumulation; 8/ and they are essential as an operating guide for aeration.

8/ See footnote 2, page 2.

Growth Through Agricultural Progress